Non-contact Measurement of Biological Signals Using Microwave Radar

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Abstract. The objective of this study was to develop a prototype system to monitor biological signals using microwave radar, without making contact with the body and without removing clothing. The prototype system has a microwave Doppler radar antenna with a 24-GHz frequency and approximately 7-mW output power. Experiments were conducted with a group of subjects. We found that the prototype system precisely captured the heart rate and the heart-rate variability (HRV). Our prototype system allows for the monitoring of biological signals, without placing any burden on the monitored individuals

Keywords: Non-contact, Microwave, heartbeat.

1 Introduction

To monitor the autonomic activation induced by mental stress without placing any burden on the monitored individual, we developed a non-contact autonomic monitoring method using a 24-GHz compact microwave radar. We have previously reported non-contact methods to monitor the heart and respiratory rates in experimental animals exposed to toxic materials or under a hypovolemic state to determine the pathophysiological condition of the subject, such as exposure to toxins or shock induced by hemorrhage [1, 2, 3]. Single photon emission tomography (SPECT) with a radioisotope (99mTe-FBPBAT) can successfully map the autonomic nervous system but is impractical for autonomic activation monitoring due to the need for large-scale equipment [4]. Using continuous electrocardiography (ECG) with conventional electrodes, rhythmic components of heart-rate variability (HRV) can be assessed using power spectral analysis, and modifications in autonomic activities induced by mental stress have been reported in the HRV power spectra [5, 6]. However, long-term electrocardiographic monitoring using electrodes places a heavy burden on the monitored individuals.

To determine human stress while driving or operating equipment, we monitored human autonomic activation induced by stressful temperatures using non-contact

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measurement of HRV with a 24-GHz compact microwave radar, which can easily be attached to the rear surface of the back of a chair without using either radioisotopes or electrodes.

2 System Design of a Prototype System Using Microwave Radar

The prototype system we designed consisted of a microwave Doppler radar antenna (TAU GIKEN Co., Yokohama, Japan), a device for controlling the power supply to this antenna, and a PC for analyzing the output data from the antenna. The frequency of this microwave radar antenna was 24 GHz, with a normal average output power of approximately (the maximum output power is less than l0 mW). The diffusion angle (θ_d) of the microwave radar antenna is approximately 40°, the antenna gain is 10 dBi, and the electrical intensity is 0.7 mW/cm^2.

Damage caused by electromagnetic waves has been discussed in the literature, particularly in the case of human applications. At frequencies greater 3 GHz, the electrical field intensity limit is set according to the guidelines for radio waves established by the Telecommunication Bureau of the Ministry of Internal Affairs and Communication in Japan. The electrical field intensity of this microwave radar is 0.7; it is therefore in conformity with the guidelines. Furthermore, the 24-GHz frequency of our device is within the frequency band for normal use of radio waves, as approved by the Japanese law.

Before input into a PC for analysis, data were acquired at a sampling frequency of 100 Hz using an A/D converter (USB6008, National Instruments, Texas, USA). After digitization, the data were analyzed by a system that we developed using analysis software (LabVIEW, National Instruments, Texas, USA). In this analyzing system, in order to reduce noise and select data related to the motion associated with the heart rate, a band-pass filter was used for transferring data from the microwave Doppler radar antenna. This filter was set between 0.5 Hz and 3 Hz; this setting covers a range of 30–180 heartbeats per minute.

3 Experiment for HRV with Prototype System

3.1 Task and Settings

Experiments to measure the heart rate and changes in the HRV using the prototype system were conducted. At the same time, the ECG was measured by the contact monitoring system using normal electrodes. We compared the results for the ECG with the results acquired by the prototype system (see Fig. 1). The prototype system was tested with four healthy male subjects (mean age 22.00 ± 0.96 years; range 21–23 years). Each subject sat on a chair with a mesh back composed of 2 layers of polyester plastic (Baron-Chair, Okamura Co., Tokyo, Japan). The distance from the antenna of the prototype system to the chair back was 120 mm, and it was placed approximately 60 mm to the left of the spine at around the level of the fourth intercostal space.

Following a silent period of 120 s, a cold pressor test was conducted for 120 s. The cold pressor test was performed for 30 s, following which there was a break for 30 s. We performed this test for 2 min, repeating the cold pressor test twice over 120 s.

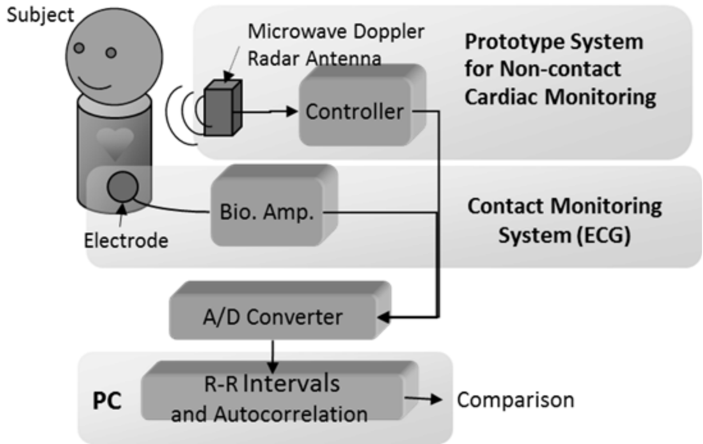

Fig. 1. Schematic diagram of apparatus for non-contact monitoring of autonomic activation

3.2 Analysis

The output signals from the prototype system and a reference precordial ECG signal from the V5 position were sampled by the A/D converter with a sampling frequency of 100 Hz. Band-pass filters were used for the prototype system outputs to reduce noise and interference. The band-pass filters were set at between 0.5 Hz and 3 Hz; this model band-pass filter covers a range of 30–180 heartbeats per minute. After filtering, the power spectra of heartbeat intervals at low frequency (LF) (0.04–0.15 Hz), high frequency (HF) (0.15–0.4 Hz), and LF/HF [7, 8] were calculated to monitor the HRV by using the maximum entropy method (MemCalc software, GMS Co., Tokyo, Japan); this method is normally used for medical research [9, 10].

The intervals of the peaks in amplitude in the outputs from the prototype system were assumed to correlate with the R-R interval for the ECG, and HRV was calculated by using peak-to-peak intervals in the output signal of the prototype system. The power spectra of the HRV (i.e., LF, HF, and LF/HF) for the R-R intervals derived by the ECG were also calculated by using the MemCalc software.

4 Results

When the subjects sat on a chair, the compact microwave radar output through the control unit showed a cyclic oscillation, corresponding to the ECG (Fig. 2). As can be seen in Fig. 2 (radar), cyclic oscillation synchronization with the occurrence of the R-wave of the ECG was confirmed.

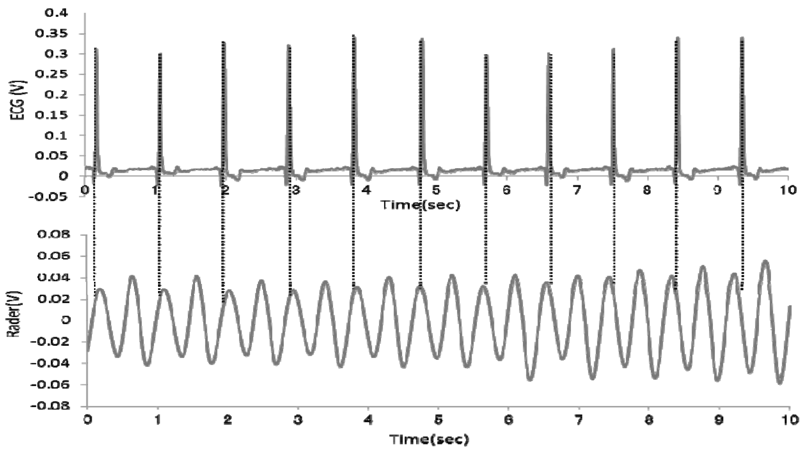

Fig. 2. A compact microwave radar output showing a cyclic oscillation that corresponds to the cardiac oscillation measured by ECG

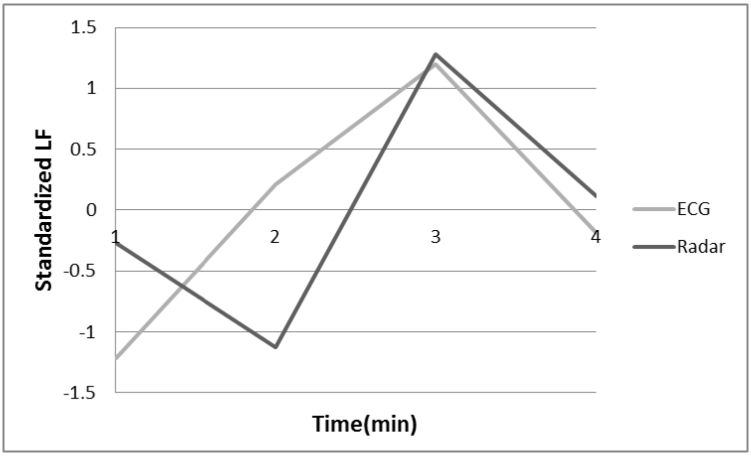

Fig. 3. In both non-contact and contact measurement, LF of a sbject (reflecting sympathetic activation) shows a peak during cold stimuli

In both non-contact (compact microwave radar) and contact (ECG as reference) measurements, the HRV parameter, LF of a subject, reflecting mainly sympathetic activation, showed a peak during cessation of the cold pressor test (Fig. 3). The mean LF of four subjects measured by non-contact and contact methods during cold stimuli increased, respectively, as compared with those of the silent period before cold stimuli.

The HF activity of the same subject, reflecting the parasympathetic activity, did not show any distinctive change during cold stimuli (Fig. 4), and the mean HF of the four subjects increased very little during cold stimuli in both the non-contact and the contact measurements.

The LF/HF activity of the same subject, reflecting sympathovagal balance, exhibited a peak during cold stimuli (Fig. 5). The mean of the four subjects measured by non-contact and contact methods during cold stimuli increased, respectively, as compared with that during the silent period before cold stimuli.

Without using radioisotopes or electrodes, stress-induced autonomic activation was monitored.

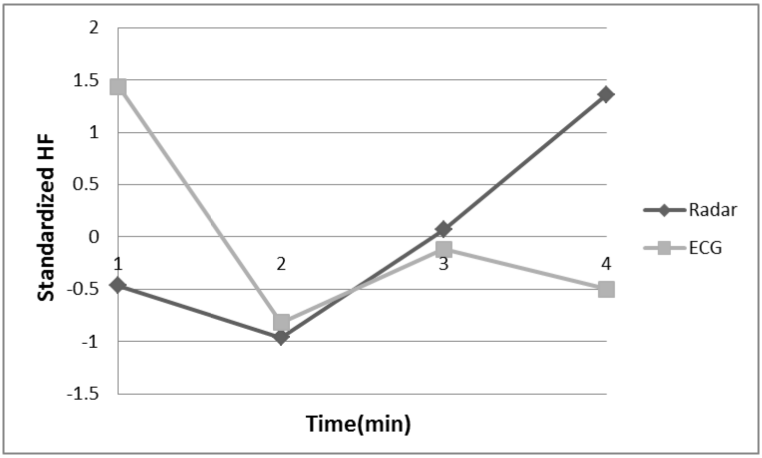

Fig. 4. In both non-contact and contact measurement, HF of a sbject (reflecting sympathetic activation) did not show any distinctive change during cold stimuli

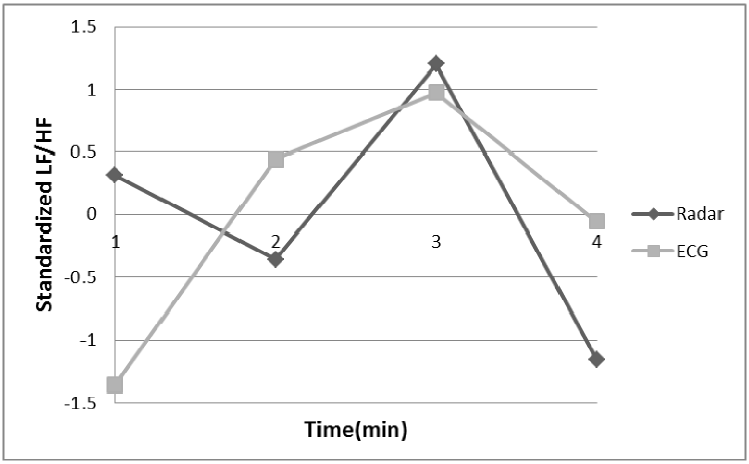

Fig. 5. In both non-contact and contact measurement, LF/HF of a sbject (reflecting sympathetic activation) exhibits a peak during cold stimuli

5 Discussion

We developed a prototype system using a 24-GHz microwave radar for non-contact cardiac monitoring. As compared with other noninvasive measurement methods (e.g., methods involving the use of strain gauges [11], pressure sensors [12], and PVDF sensors [13]), our method is completely non-contact and furthermore does not require the removal of clothing. We designed the antenna with relatively small dimensions to obtain high gain with high spatial resolution; the small size also reduces the possibility of signal absorption through the human body, which at 24 GHZ is more than that at lower frequencies. In addition, a high gain allows a smaller area to be analyzed. As a result, a small antenna at 24 GHz is easier to integrate into a monitoring system and is suitable for civil applications. The device can be produced at low cost, which makes it competitive, when produced on a large scale. On the other hand, the signal processing required is delicate, because there is a space between the body and the microwave radar antenna, and it is susceptible to other body motions. These disadvantages are compensated for by the relatively high antenna gain at 24 GHz, which enables better spatial resolution. The mean LF, which mainly reflects sympathetic activity during cold stimuli, is significantly higher than the mean LF of the silent period before cold stimuli. The HF indicating the parasympathetic activity changed very little during the cold stimuli. This can be attributed to the activation of the sympathetic nervous system induced by stressful temperature. Without using radioisotopes or electrodes, our system monitors sympathetic activation through the back of a chair. Mental stress affects the autonomic nervous system [5, 6]. Moreover, there is a relationship between mental stress and traffic accidents. By issuing auto nomic activation early warnings, it may be possible to prevent industrial accidents.

6 Application

We carried out the detection of abnormal breathing using a prototype system. Subjects simulating abnormal breathing were measured using the prototype system. Figure 6 shows the results of the respiratory pattern of the subjects, acquired from the prototype system and ECG as reference. The oscillation halted for approximately 30 s after continuing short-period oscillations, and Cheyne-Stokes respiration was confirmed. This trend can be seen in both the ECG and the prototype system. Moreover, the start and end time of the apnea period was the same in the ECG and the prototype system. These results show that a prototype system to detect apnea is possible with high accuracy. Therefore, a prototype system would be possible for the measurement of respiratory activity.

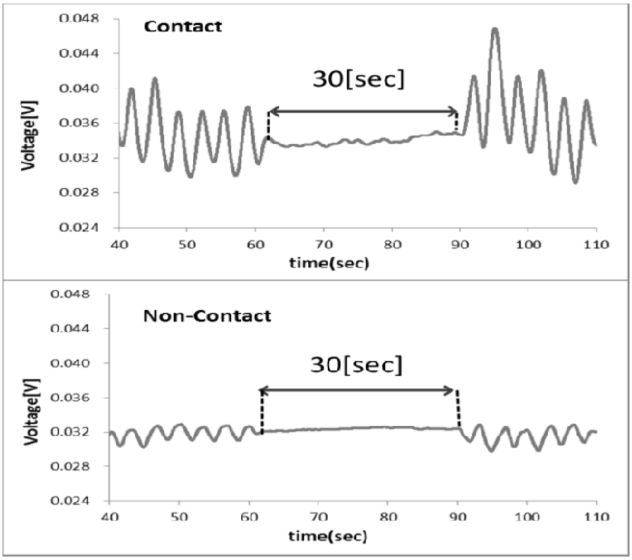

Fig. 6. The oscillation halted for approximately 30 s after a continuous short period, and Cheyne-Stokes respiration was confirmed

7 Conclusion

In this paper, we describe a novel prototype system using microwave radar for non-contact cardiac monitoring that requires neither direct contact with the body nor the removal of clothing. The antenna of our prototype system is relatively small and can easily be attached to furniture in the workplace. This means that the device is suitable for civil applications at a low cost. We will examine its actual use in various settings in the future.

We monitored human autonomic activation induced by a chilled water load through non-contact measurement of heart rate variability using a compact microwave radar. The results confirmed that the intervals captured by our prototype system are similar to the intervals captured by the ECG signal because the estimated heart rates determined by using the data captured by our prototype system are roughly in accordance with the actual measurements. Results confirmed that our microwave system can capture information similar to that obtained with the ECG system. In addition, the changes in the HRV measured by both methods were also similar, although there were some differences in the absolute values. These results mean that our prototype system can capture signals with sufficient accuracy to calculate the heart rate and HRV.

The long-term monitoring of HRV can be used as a diagnostic test for sepsis [14]. Moreover, it has been reported that a reduction in the HRV is useful in identifying septic patients at risk of the development of a multiple organ dysfunction syndrome (MODS) [15]. Our method of noncontact monitoring for HRV can thus be used not only for monitoring autonomic activation but also as a future diagnostic method for sepsis or as a predictor of MODS, without touching the patient. Zheng et al. [16] have proposed a wearable health care system for long-term continuous vital sign monitoring of high-risk cardiovascular patients. Our system does not require special gear and may be suitable for the screening of high-risk patients as part of a health check.

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